The combined use of CALIOP, MODIS and OMI level 2 aerosol products for calculating direct aerosol radiative effects

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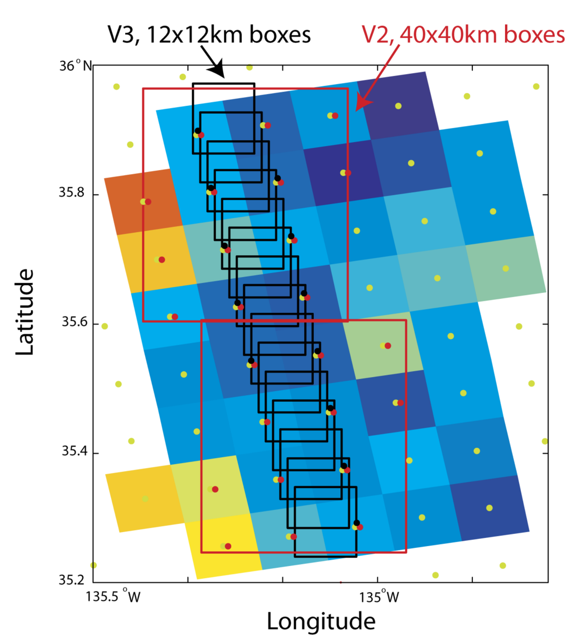
Abstract

We describe a technique for combining CALIOP aerosol backscatter, MODIS spectral AOD (aerosol optical depth), and OMI AAOD (absorption aerosol optical depth) measurements for the purpose of calculating direct aerosol radiative effects. In the first step of our strategy for combining these data sets we seek to find combinations of bi-modal microphysical aerosol particle models that are reconcilable with the MODIS, OMI and CALIOP observations within the uncertainties of their respective retrievals. In a second step, we use these models to forward calculate the aerosol radiative properties required for a full assessment of the direct aerosol radiative forcing, i.e., spectral extinction/AOD, single scattering albedo and asymmetry parameter. In the final step, we use a radiative transfer model to determine how the range of microphysical retrievals translates into a range of radiative forcing estimates. We show sensitivity studies and first results from actual collocated CALIOP V3, MODIS and OMI data collected in October 2007.

As a prerequisite for the application of our methodology to the actual satellite observations, we assessed the consistency between comparable measurement quantities from the different A-Train sensors. In particular, for eight months (Jan., Apr., July, Oct. 2007 and 2009), comparisons of the standard MODIS-Aqua (Collection 5) AOD data to the AOD calculated from the latest release (Version 3) of the CALIOP level-2 aerosol extinction profile data set show an order of magnitude increase for the CALIOP V3 data density by comparison to V2. Differences in global, monthly mean, over-ocean AOD (532nm) between CALIOP and MODIS range between 0.02 and 0.06 for CALIOP V2, and between 0.025 and 0.04 for CALIOP V3, with CALIOP generally biased low. Mean differences in instantaneously collocated AOD retrievals by the two instruments are reduced from values of greater than 0.1 using CALIOP V2 to values near 0.07 for CALIOP V3. A restriction to scenes with cloud fractions below 1% (as defined in the MODIS aerosol retrievals) generally results in improved correlation (r^2>0.5). For AOD at 1064nm, there is equal improvement between CALIOP V2 and V3, with the mean in instantaneously collocated AOD differing by generally 0.06 or less between the two instruments.

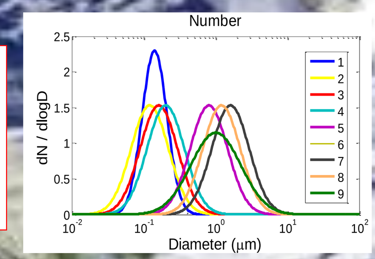
As a test of our methodology, we applied our multi-sensor retrievals of aerosol radiative properties to airborne HSRL (High Spectral Resolution Lidar) aerosol backscatter data, sunphotometer derived AOD, and in situ aerosol absorption measurements in a fire plume study during the ARCTAS (Arctic Research of the Composition of the Troposphere from Aircraft and Satellites) field campaign in 2008. Radiative fluxes modeled based on the multi-sensor aerosol retrievals compare well with radiative fluxes measured by an airborne spectral flux radiometer (SSFR) aboard the same aircraft. We found good agreement for the entire SSFR wavelength range of 350-2150 nm, indicating the validity of our approach for determining spectral radiative properties from spectrally limited retrieval input.

Comparison geometry: CALIPSO V2 vs. CALIPSO V3 vs. MODIS MYD04_L2 AOD



Methodology: Retrieval of aerosol radiative properties from A-Train observations (or suborbital measurements)

Constraints/Input:
- MODIS/AATS AOD (7/2 λ) + δAOD
- OMI/In situ AAOD (450 nm) + δAAOD
- CALIPSO/HSRL ext (532, 1064 nm) + δext
- CALIPSO/HSRL back (532 , 1064 nm) + δback



MODIS aerosol models:
4 fine and 5 coarse mode distributions define standard deviation and refractive indices of bi-modal log-normal size distribution → 20 combinations
Free parameters: N_{fine}, N_{coarse}

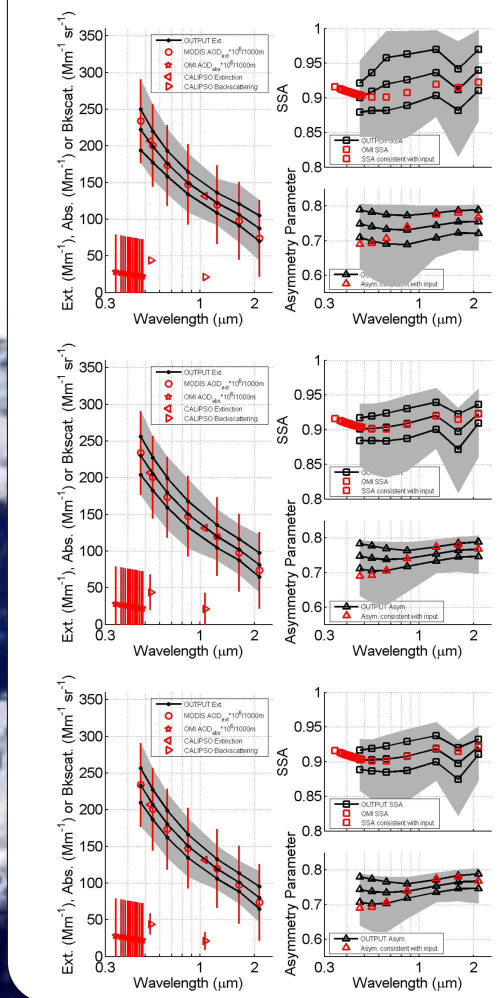
Comparison:
CERES/SSFR+AATS
$\Delta F_{aerosol}$

Target:
$\Delta F_{aerosol}(z) + \delta\, \Delta F_{aerosol}(z)$

Rtx code

Retrieval:
ext (λ, z) + δext
ssa (λ, z) + δssa
g (λ, z) + δg

Constraints provided by CALIOP β_{532}

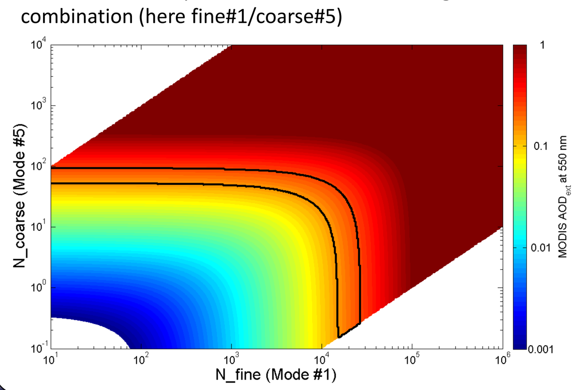


MODIS AOD: (±0.03±5%)
OMI AAOD: (±0.03±5%)
No CALIOP β_{532}

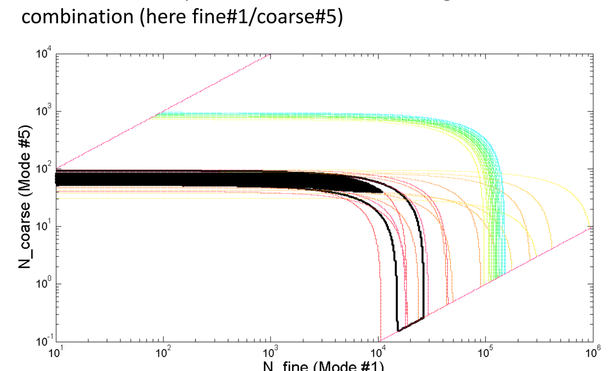
MODIS AOD: (±0.03±5%)
OMI AAOD: (±0.03±5%)
CALIOP: β_{532} (±20Mm^{-1}±10%)

MODIS AOD: (±0.03±5%)
OMI AAOD: (±0.03±5%)
CALIOP: β_{532} (±10Mm^{-1}±10%)

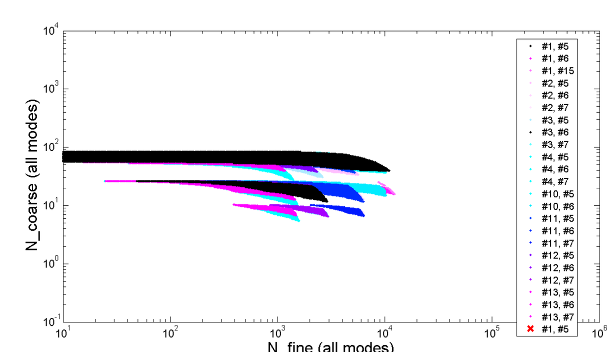
Methodology: Step 1
Each observable (here AOD 550nm) is consistent with a range of fine/coarse mode particle concentrations for a given fine/coarse mode combination (here fine#1/coarse#5)



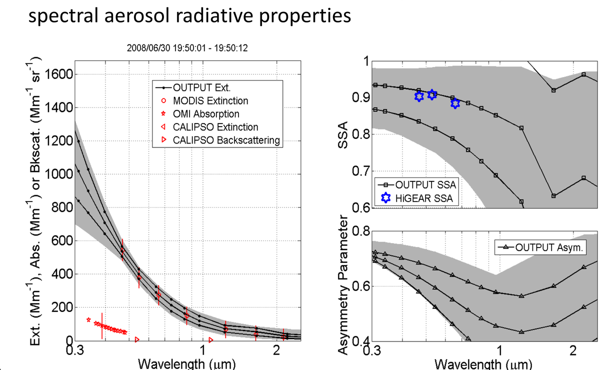
Methodology: Step 2
The totality of all observables is consistent with a smaller range of fine/coarse mode particle concentrations for a given fine/coarse mode combination (here fine#1/coarse#5)



Methodology: Step 3
For all possible fine/coarse mode combinations, the observables are consistent with a set of fine/coarse mode particle concentration ranges

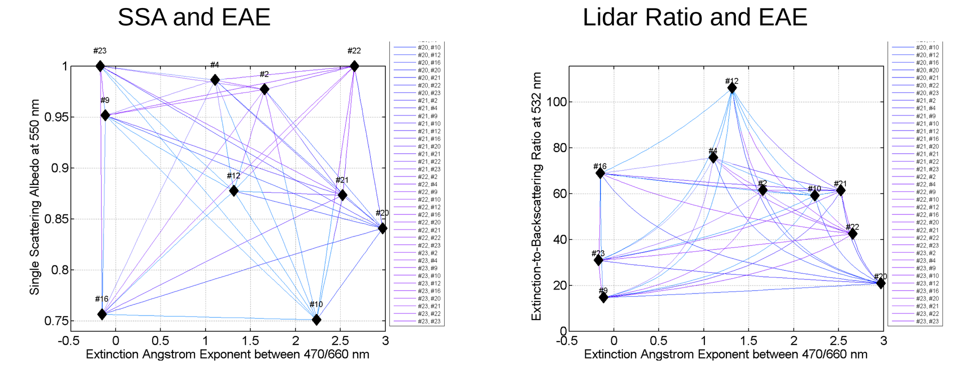


Methodology: Step 4
A projection of the (best 10%) concentration ranges (wedges above) onto aerosol radiative property contours (not shown) yields a range of spectral aerosol radiative properties

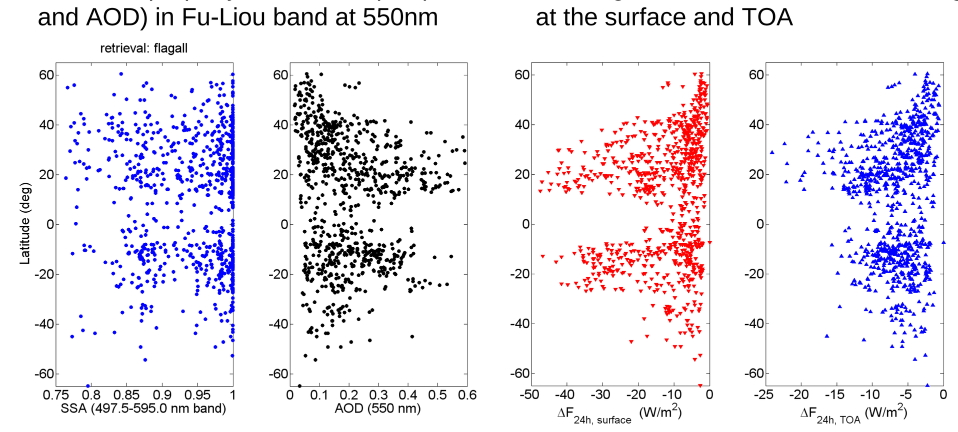


Application 1: 1 month data set - October 2007

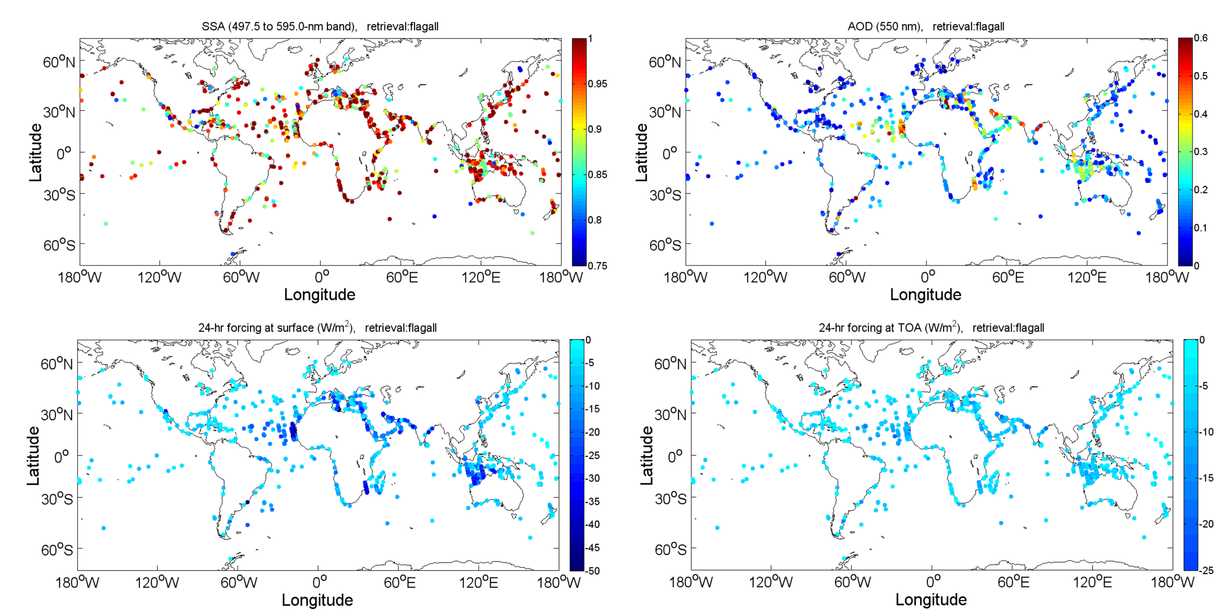
Use 7 fine + 3 coarse models, for model combinations



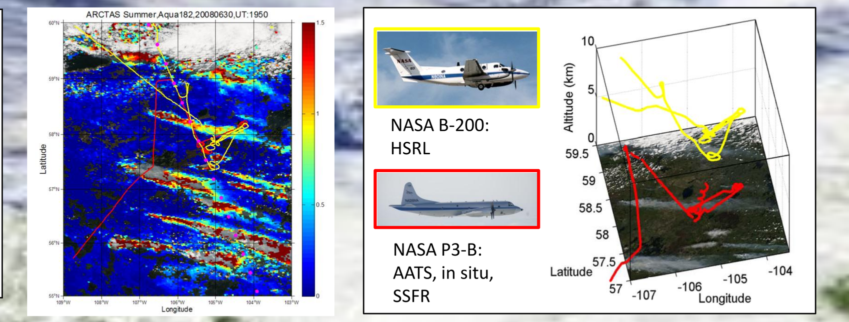
Proof of concept: MOC retrieval output and calculated radiative effects



Proof of concept: 24h-avg aerosol radiative forcing calculated from combined CALIOP, MODIS, OMI observations for October 2007

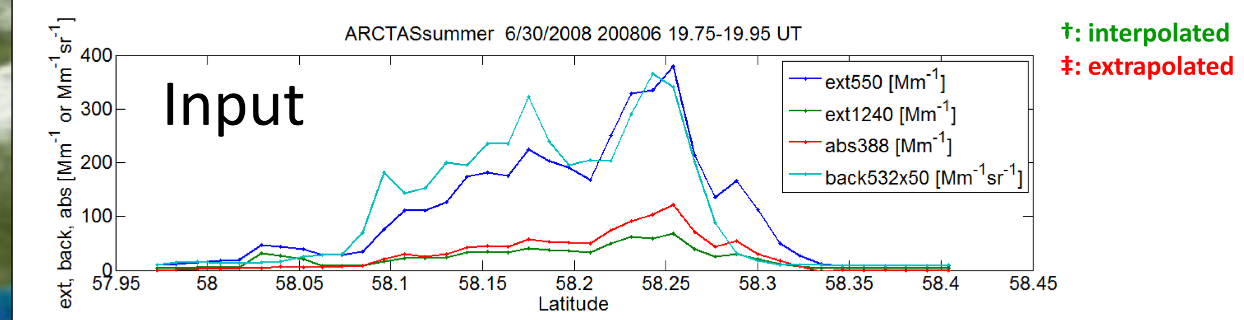


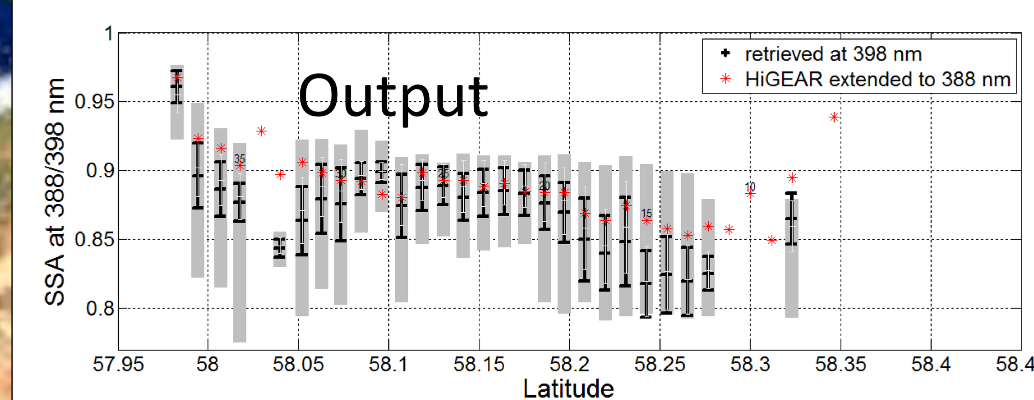
Application 2: Test of method with suborbital data



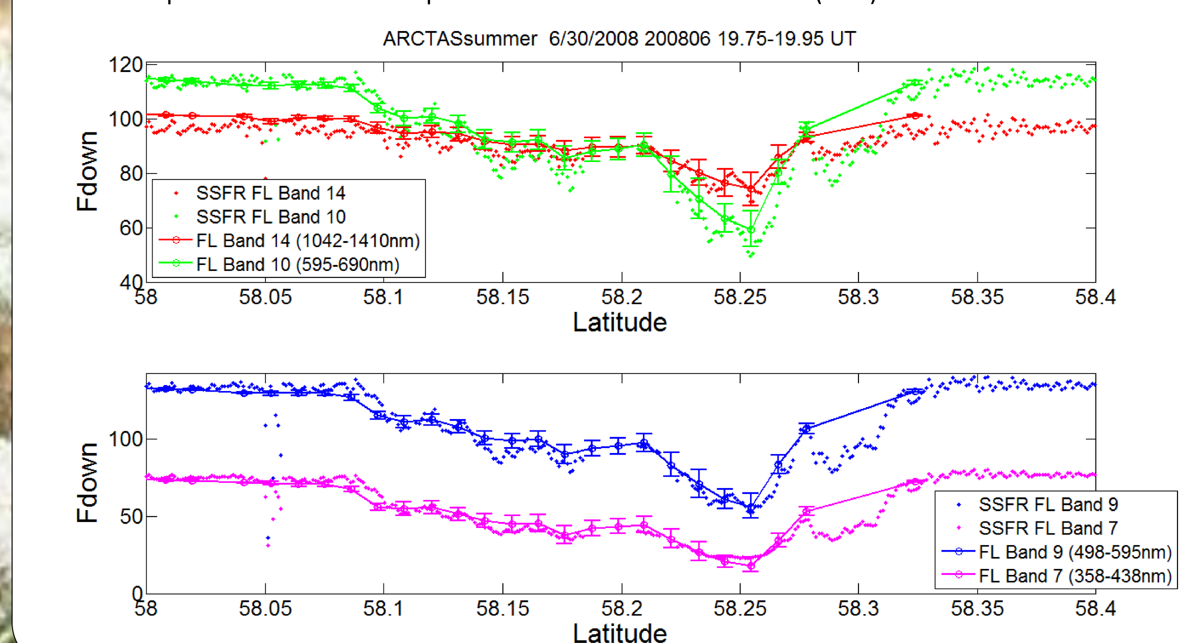
Test of method with suborbital and reduced input data:

AATS AOD/ext @ 550/1240† nm, HSRL backscatter @ 532nm, in situ absorption @ 388nm‡





Test of Methodology:
Use aerosol radiative properties in a radiative transfer model and calculate spectral radiative fluxes for comparison with airborne spectral flux observations or CERES (TOA)

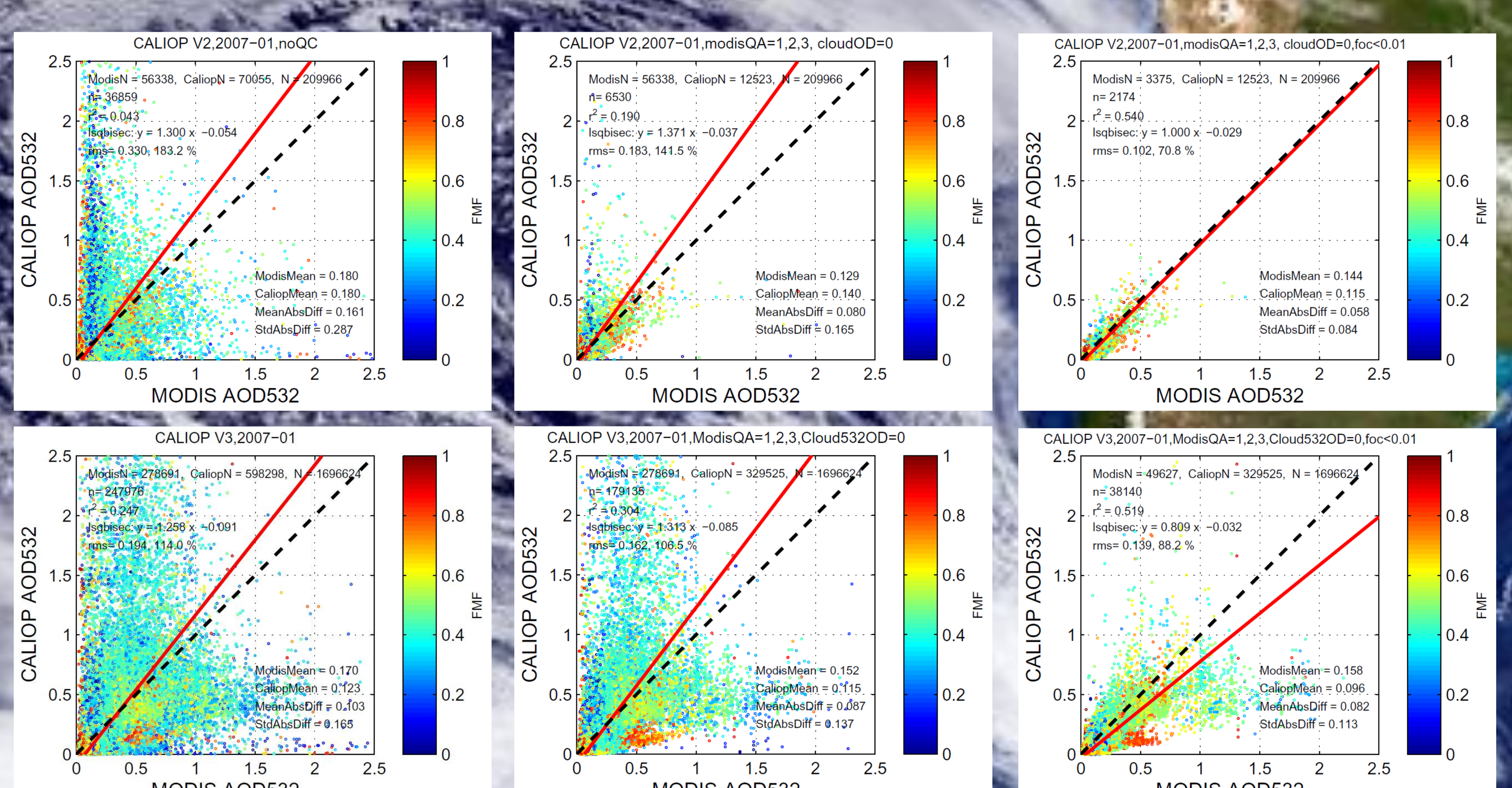


Comparison of CALIOP V2 and V3 AOD(532nm) to collocated MODIS MYD04_L2

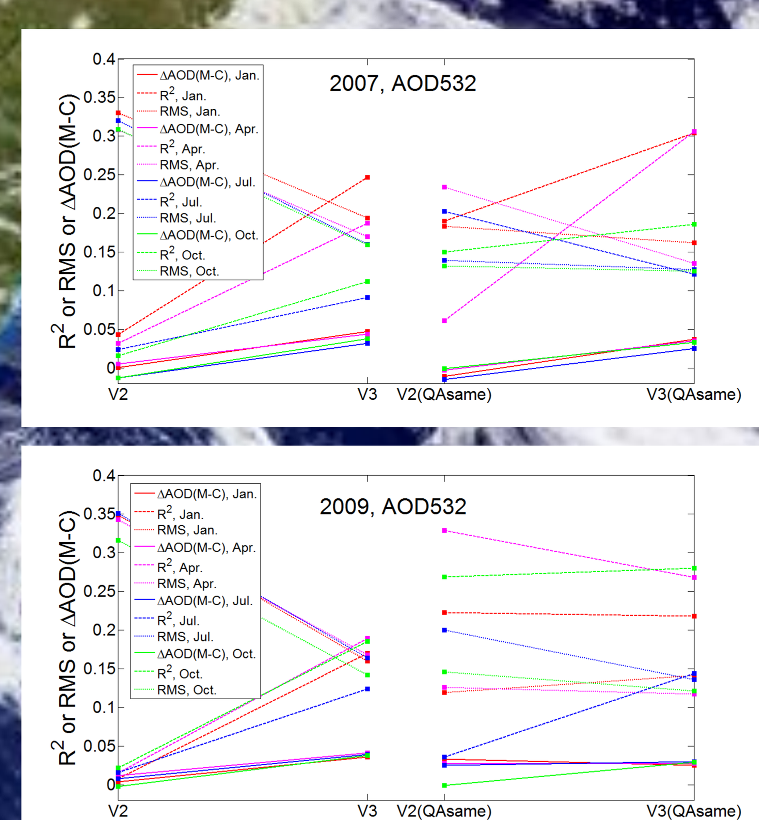
no QA | MODISQA=1,2,3, CALcloudOD=0 | QA and cloud < 1%

Jan. 2007 CALIOP V2

Jan. 2007 CALIOP V3

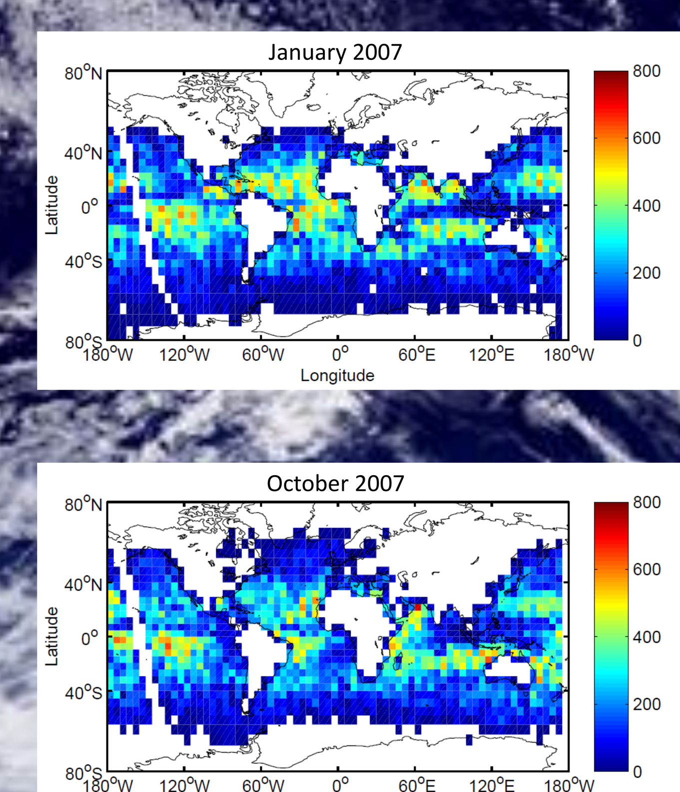


Statistical comparison for 8 months (Jan., Apr., Jul., Oct. 2007 & 2009)

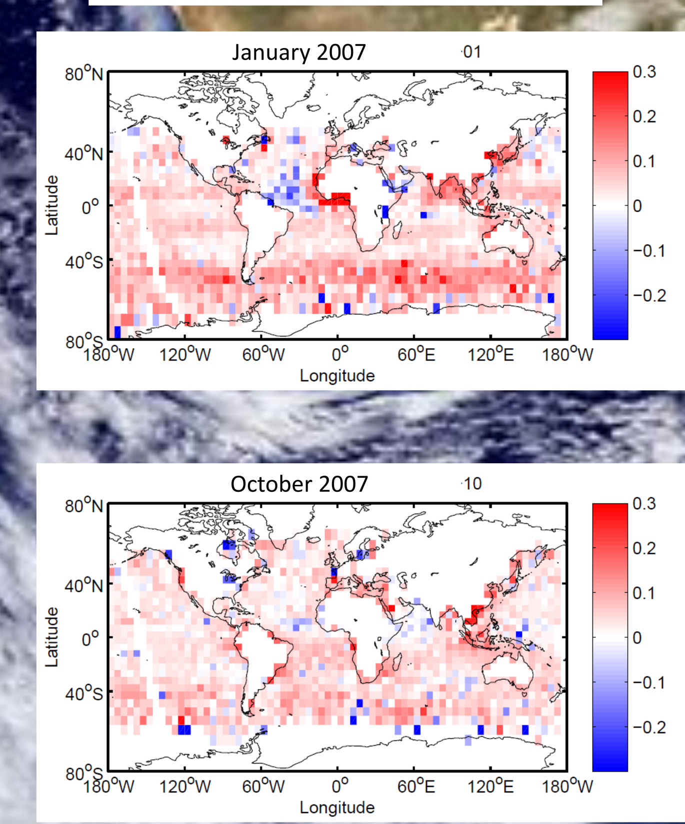


Comparison of CALIPSO V3 to MYD04_L2 for Jan. and Oct. 2007

Data count per 1x1 degree box



ΔAOD (M-C) in 1x1 degree box



Conclusions

Retrieval of aerosol radiative properties from CALIPSO, MODIS and OMI:

A. We have developed a methodology for the retrieval of spectral aerosol radiative properties from collocated AOD, AAOD and aerosol backscatter data as provided by the formation flying of the MODIS, OMI and CALIOP instruments in the A-Train constellation of satellites.
B. In a first application of our methodology to airborne testbed data, radiative fluxes modeled based on the multi-sensor aerosol retrievals compare well with radiative fluxes measured by an airborne spectral flux radiometer aboard the same aircraft, indicating the validity of our approach for determining spectral radiative properties from spectrally limited retrieval input.
C. An application of our methodology to the CALIOP/MODIS/OMI(OMAERUV) data in October 2007 yields only a small number (~800) of collocated retrievals.
D. Maximum 24h-aeraged direct aerosol radiative forcing at TOA is of the order of -20 Wm^{-2} and +40Wm^{-2} at the surface.

Comparison of CALIPSO V2 and V3 AOD to MODIS MYD04-L2 AOD for eight months of data:

A. Differences in global, monthly mean, over-ocean AOD (532nm) between CALIOP and MODIS range between 0.02 and 0.06 for CALIOP V2, and between 0.025 and 0.04 for CALIOP V3, with CALIOP generally biased low.
B. RMS-differences in instantaneously collocated AOD retrievals by the two instruments are reduced from values of greater than 0.3 using CALIOP V2 to values near 0.15 for CALIOP V3.
C. An application of quality flags in both data sets and/or restrictions to scenes with cloud fractions below 1% generally results in improved correlation (r^2>0.5).
D. For AOD at 1064nm, there is equal improvement between CALIOP V2 and V3, with the mean in instantaneously collocated AOD differing by generally 0.06 or less between the two instruments.